Opteron and AMD64
A Commodity 64 bit x86 SOC

Fred Weber

Vice President and CTO

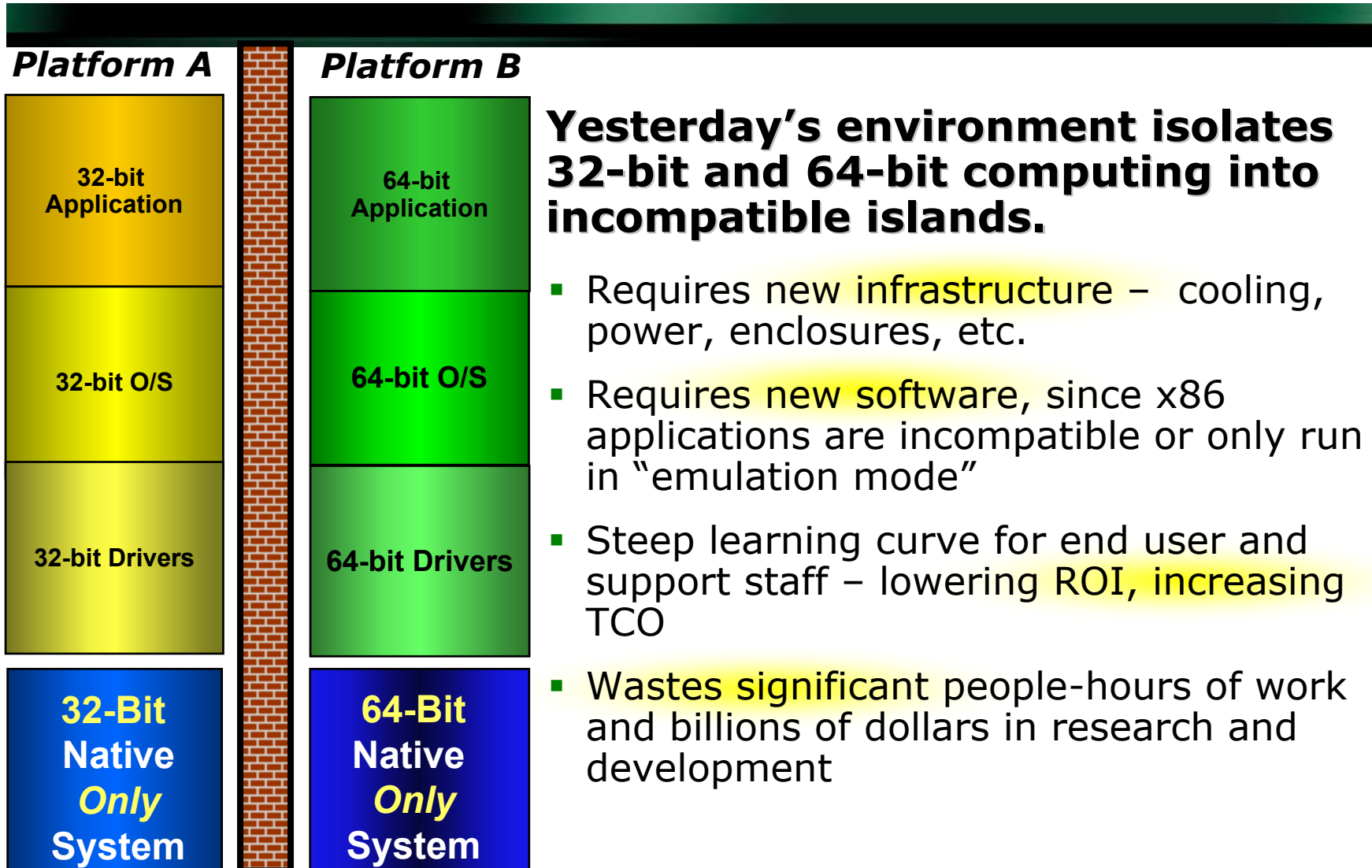Computation Products Group
Advanced Micro Devices

Opteron/AMD64 Launch – Today!

AMD

- Official Launch of AMD64 architecture and Production Server/Workstation CPUs
  - Series 200 (2P) available today
  - Series 800 (4P+) available later in Q2

- <u>Oracle, IBM-DB2, Microsoft</u>, RedHat, SuSe software support
  - And many others

- Dozens of server system vendors
  - System builder availability this quarter
  - <u>IBM</u> systems available 3Q03

- Lots of public benchmarks

Before AMD64:

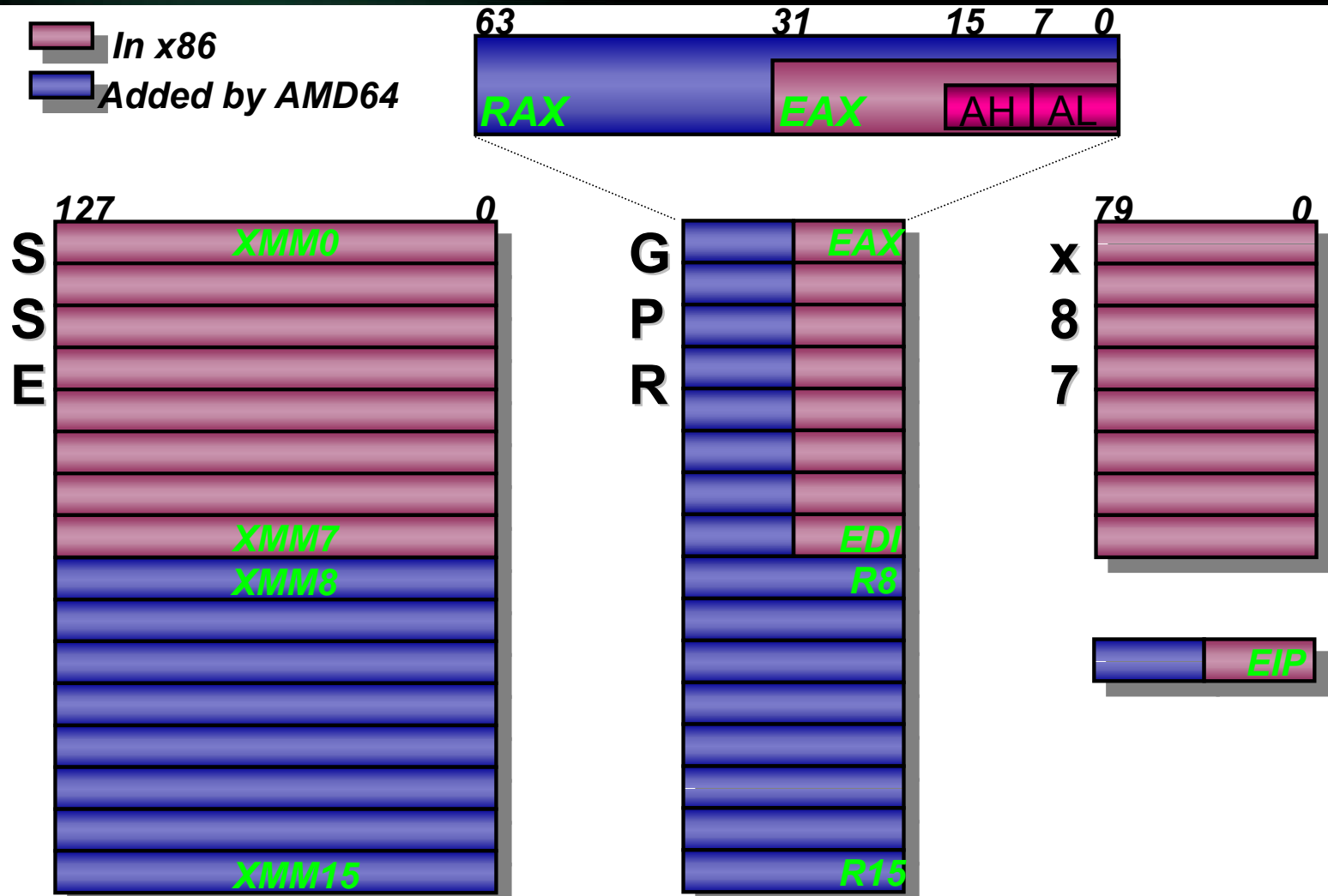*Computing & infrastructure islands on either side of the wall*

AMD

Platform A

| 32-bit Application |
| 32-bit O/S |
| 32-bit Drivers |

32-Bit Native *Only* System

Platform B

| 64-bit Application |
| 64-bit O/S |
| 64-bit Drivers |

64-Bit Native *Only* System

Yesterday's environment isolates 32-bit and 64-bit computing into incompatible islands.

- Requires new infrastructure – cooling, power, enclosures, etc.

- Requires new software, since x86 applications are incompatible or only run in "emulation mode"

- Steep learning curve for end user and support staff – lowering ROI, increasing TCO

- Wastes significant people-hours of work and billions of dollars in research and development

AMD's Industry Vision:
Compatible systems that bridge from 32- to 64-bit

AMD

AMD: Single Platform

32-Bit Application (3 GB limit)	32-Bit Application *(4GB limit)*	64-Bit Application
32-Bit O/S	64-Bit O/S	64-Bit O/S
32-Bit Software Drivers	64-Bit Software Drivers	64-Bit Software Drivers

AMD Opteron

- Leverages existing infrastructure
  - thermal, enclosures, power, and **BIOS**
- Runs existing <u>32-bit applications natively</u> with unsurpassed performance
  - >20% increase clock-for-clock compared to AMP Athlon™ processor
  - No tools or O/S work needed
- Runs existing 32-bit applications on 64-bit O/S
  - Take full advantage of 4GB local memory
- Allows customers to migrate to 64-bit performance according to their schedule
- Low learning curve for users and support staff

AMD64 Programmer's Model

AMD

In x86
Added by AMD64

63 31 15 7 0

RAX EAX AH AL

127 0
S S E
XMM0
XMM7
XMM8
XMM15

G P R
EAX
EDI
R8
R15

79 0
x 8 7

EIP

Opteron SOC Architecture Overview

AMD

- First AMD64 based processor

- Aggressive out-of-order, 9-issue superscalar processor

- Integrated DDR memory controller

- Leading performance in integer, floating point and multimedia
  - AMD64, x87, MMX™, 3DNow!™, SSE, SSE2

- Glueless multiprocessing through HyperTransport

- Expandable IO through HyperTransport

Opteron Architecture

DDR Memory Controller		L2 Cache
Opteron Processor Core	L1 Instruct. Cache	
	L1 Data Cache	
HyperTransport™ technology		
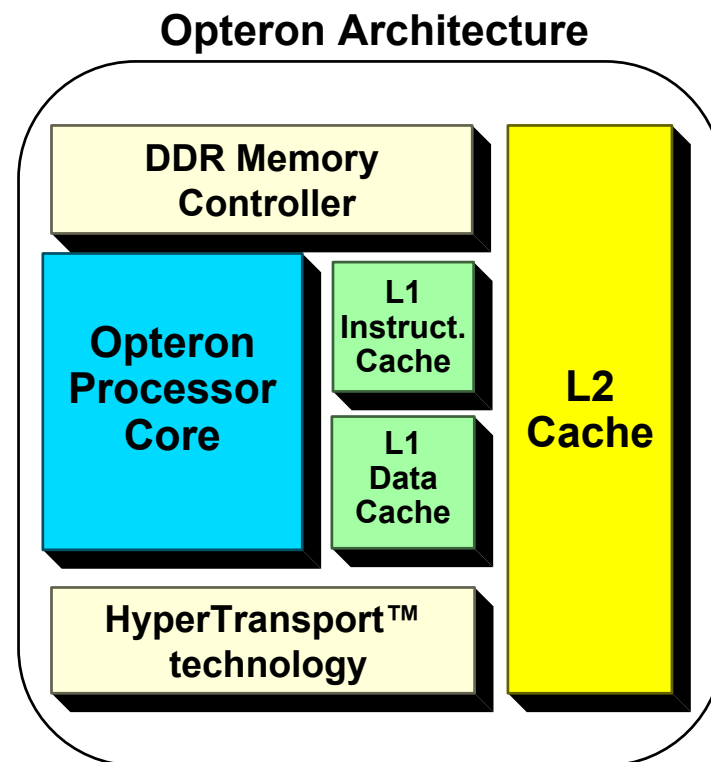
AMD Opteron™ Processor Technology Overview

AMD

- **Processor Core Overview**
  - Support for AMD's 64-bit technology
  - 12-stage int, 17-stage fp pipelines
  - Enhanced TLB structures
  - TLB flush filter
  - Enhanced branch prediction
  - Large L2 cache (up to 1MB)
  - ECC protection

- **Memory Controller Overview**
  - Dual-channel DDR memory
  - PC2700, PC2100, or PC1600 DDR memory support
  - Registered or Unbuffered DIMMs
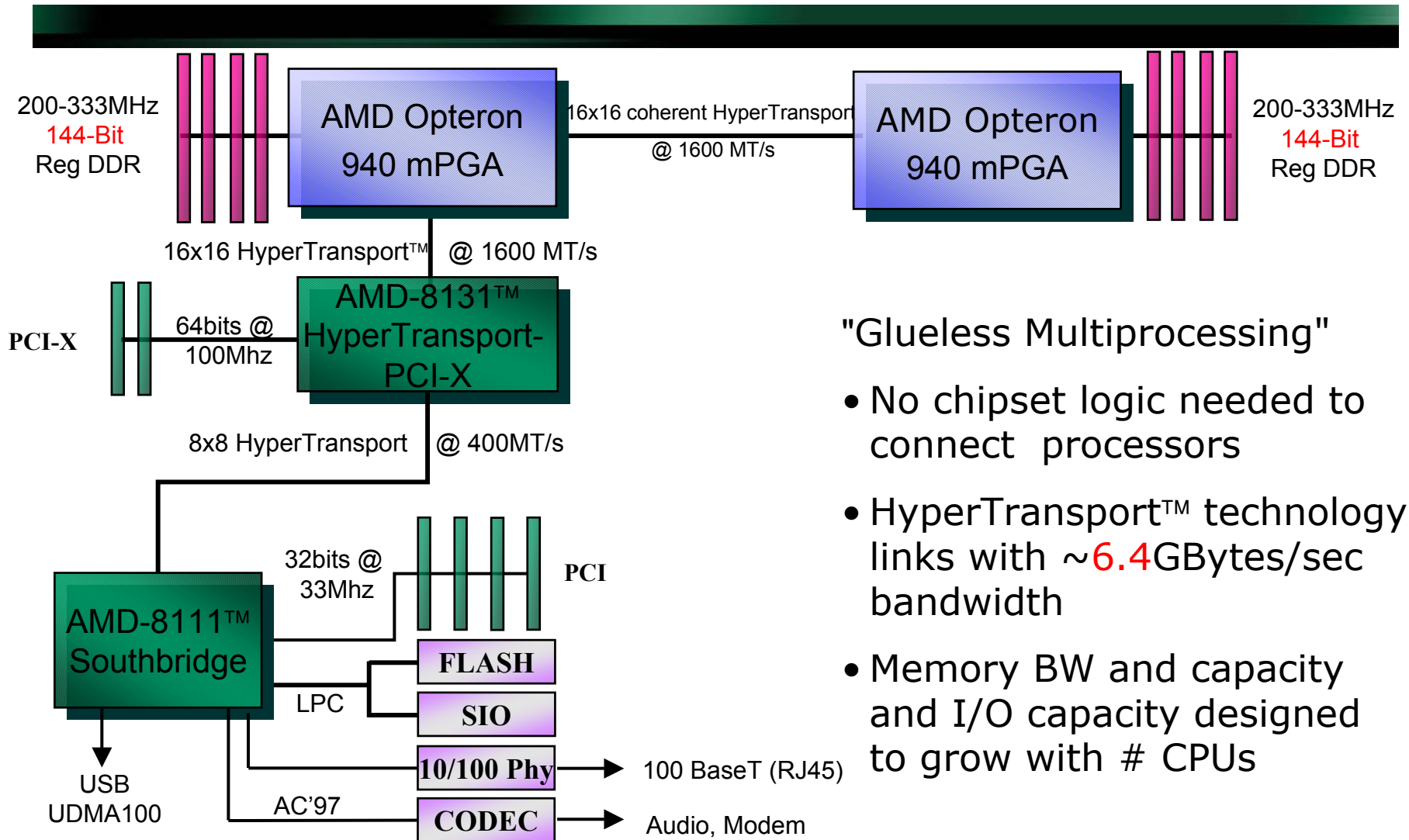 - ECC and Chip Kill
  - High bandwidth (up to **6.4GB/s**)

- **HyperTransport™ Technology Overview**
  - One, two, or three links
  - 2, 4, 8, 16, or 32-bits full duplex
  - Up to 6.4 GB/s bandwidth per link
 - **19.2 GB/s** aggregate external bandwidth

DRAM

MCT

SRQ

CPU

XBAR

HT

HT

HT
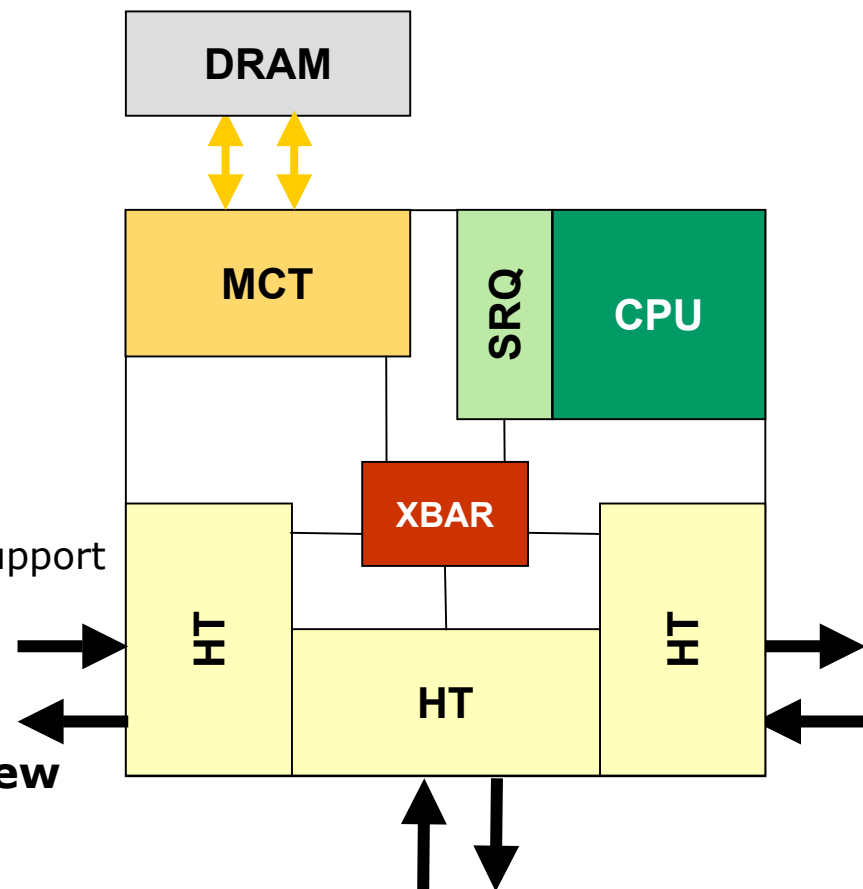
HT = HyperTransport™ technology

AMD Opteron™ processor-based 2P Server

AMD

200-333MHz
144-Bit
Reg DDR

AMD Opteron 940 mPGA

16x16 coherent HyperTransport @ 1600 MT/s

AMD Opteron 940 mPGA

200-333MHz
144-Bit
Reg DDR

16x16 HyperTransport™ @ 1600 MT/s

AMD-8131™ HyperTransport-PCI-X

PCI-X

64bits @ 100Mhz

8x8 HyperTransport @ 400MT/s

AMD-8111™ Southbridge

32bits @ 33Mhz

PCI

FLASH

LPC

SIO

10/100 Phy → 100 BaseT (RJ45)

USB
UDMA100

AC'97

CODEC → Audio, Modem

"Glueless Multiprocessing"

- No chipset logic needed to connect processors

- HyperTransport™ technology links with ~6.4GBytes/sec bandwidth

- Memory BW and capacity and I/O capacity designed to grow with # CPUs

AMD Opteron™ processor-based 4P Server

AMD

22 April 2003
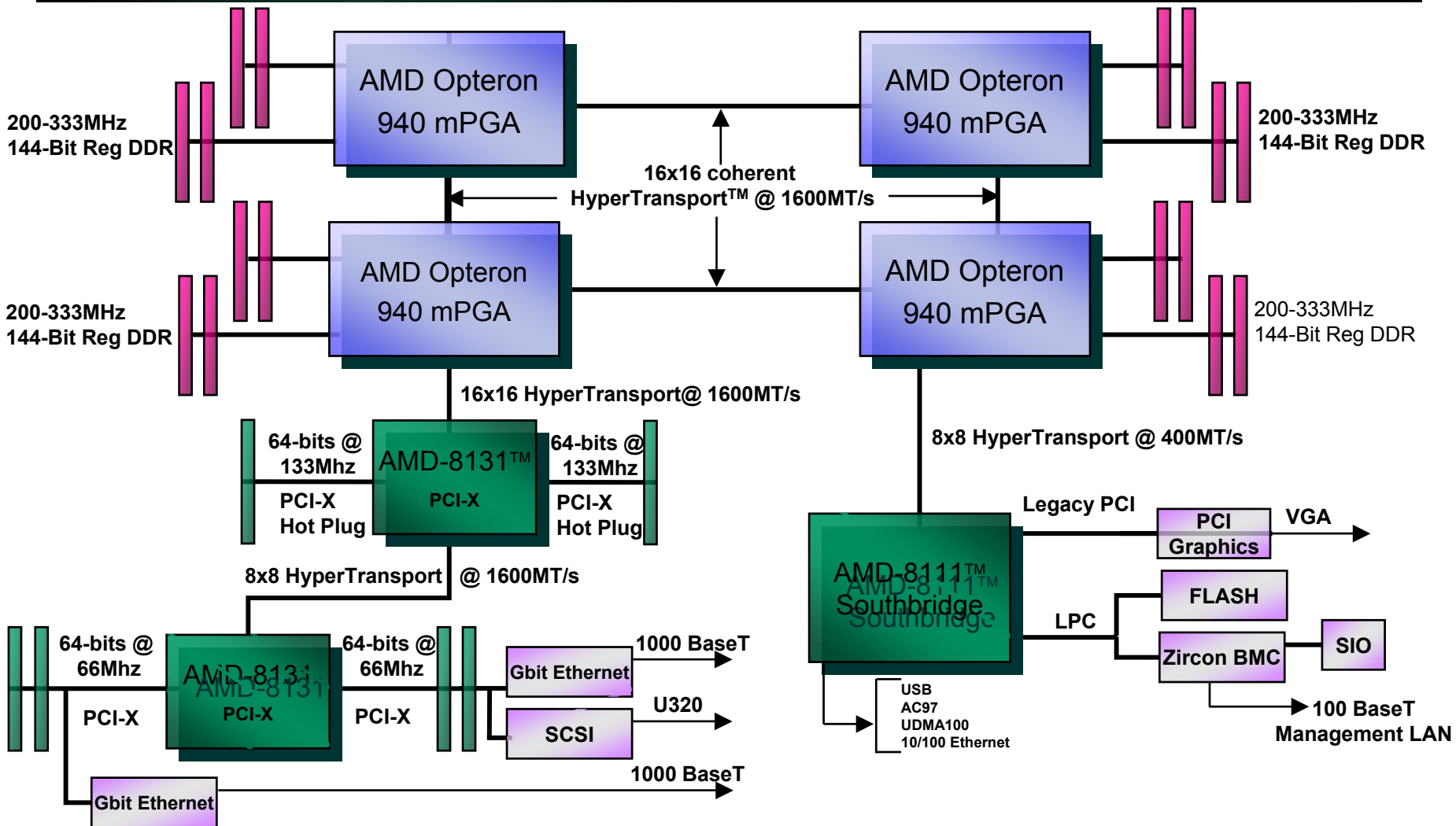
4P, 32GB AMD Opteron™ Processor System
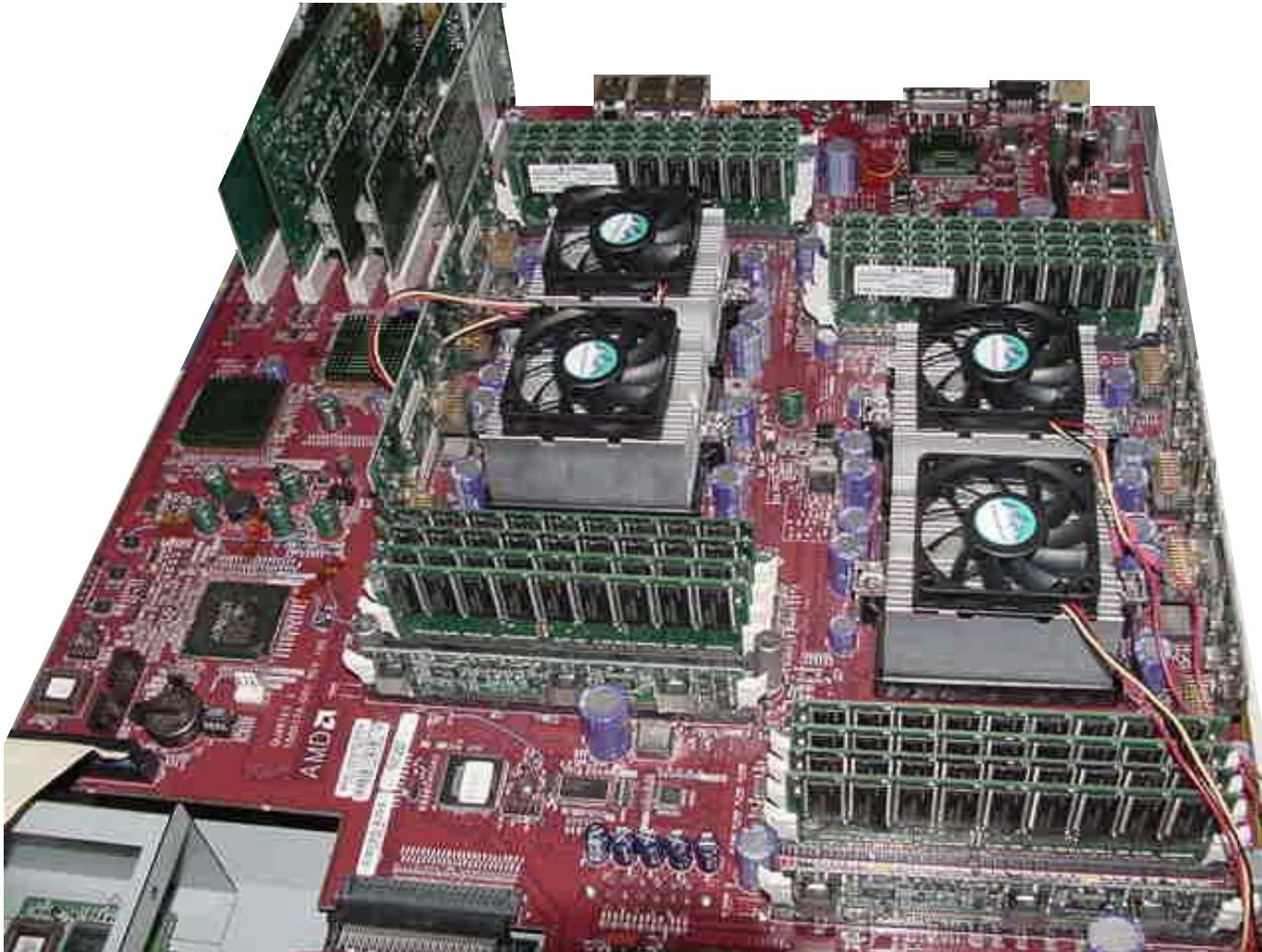
4U, 4P AMD Opteron™ processor System

AMD64 Code Quality

AMD

- GCC port alpha quality since Feb '01
  - Compiler generating alpha quality code in 50 man-months
  - Linux kernel ported in 60 man-months
  - Tool chain was straightforward port

- SpecInt2000 code quality, 64bits vs. 32 bits (using GCC 3.1.1)
  - average instruction length increased to 3.8 from 3.4 bytes
  - dynamic instruction count decreased by 10%
  - dynamic load count decreased by 26%
    - number of loads forwarded from recent stores substantially reduced
  - dynamic store count decreased by 36%
  - back to back register dependencies decreased by 10%

GCC SPECint

FORTRAN Compiler Support
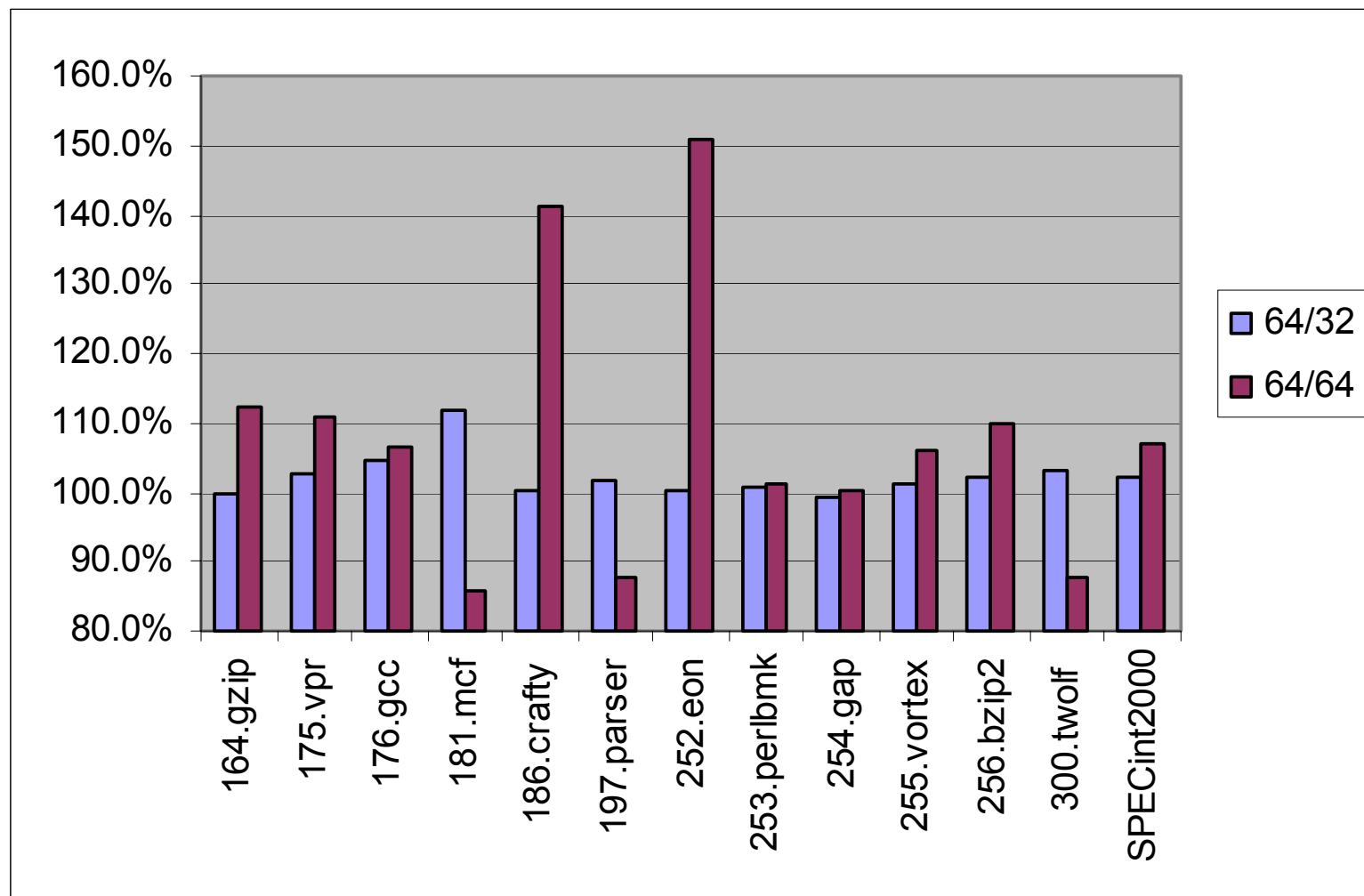
The Portland Group Compiler Technology

– AMD and STMicroelectronics are working together to bring The Portland Group Compiler Technology to AMD64

- Support will include
  - F90 & F77
    - Some F95 extensions also included
    - SPECcpu2000 explicitly supported
  - Optimized 32-bit and 64-bit code generation
  - Linux and Windows
  - OpenMP support
  - Full debugging support
- STMicro will also be developing C and C++ compilers based on same code generation technology
- Beta now, Production quality in 1H03

The Rewards of Good Plumbing

AMD 🔺

- **High Bandwidth**
  - 2P system is designed to achieve 7 GB/s aggregate memory Read bandwidth
  - 4P system is designed to achieve 10 GB/s aggregate memory Read bandwidth
    - With data spread uniformly across the nodes

- **Low Latency**
  - Average 2P unloaded latency (page hit) is designed to be < 120 ns
  - Average 4P unloaded latency (page hit) is designed to be < 140 ns
  - Latency under load increases slowly due to excess Interconnect Bandwidth
  - Latency shrinks quickly with increasing CPU clock speed and HyperTransport link speed

Integrated Memory Controller
Latency (Local Memory Access, Registered Memory, CAS2)

AMD

Read Latency Accessing Local Memory, PC2100

Legend:
- PageHit 0 Hop
- PageMiss 0 Hop
- Prb Miss 1 Hop (2 node case)
- Prb Miss 2 Hop (4 node case)

X-axis: Frequency (MHz)
Y-axis: Latency (ns)

Memory Bandwidth

Floating-Point Performance
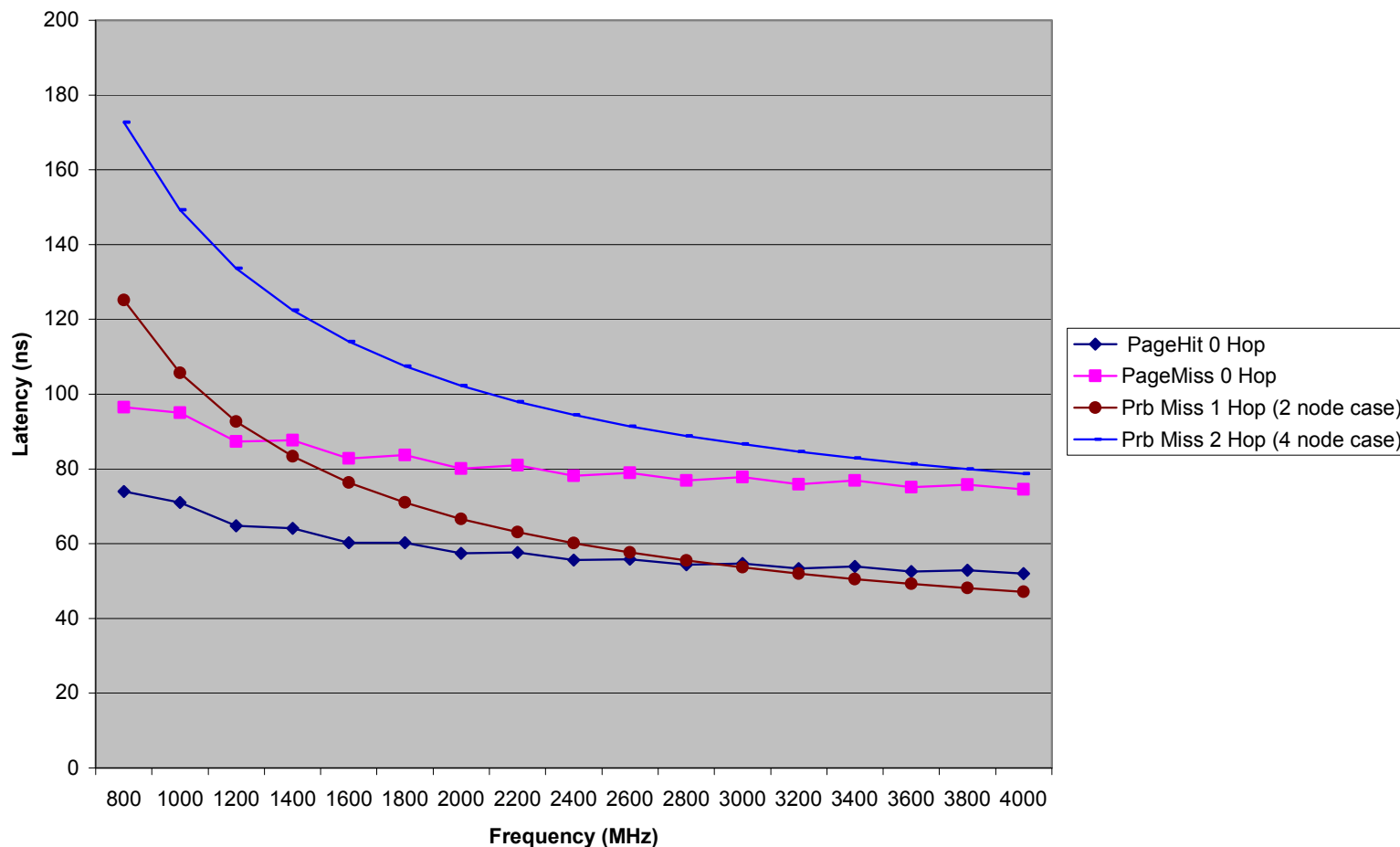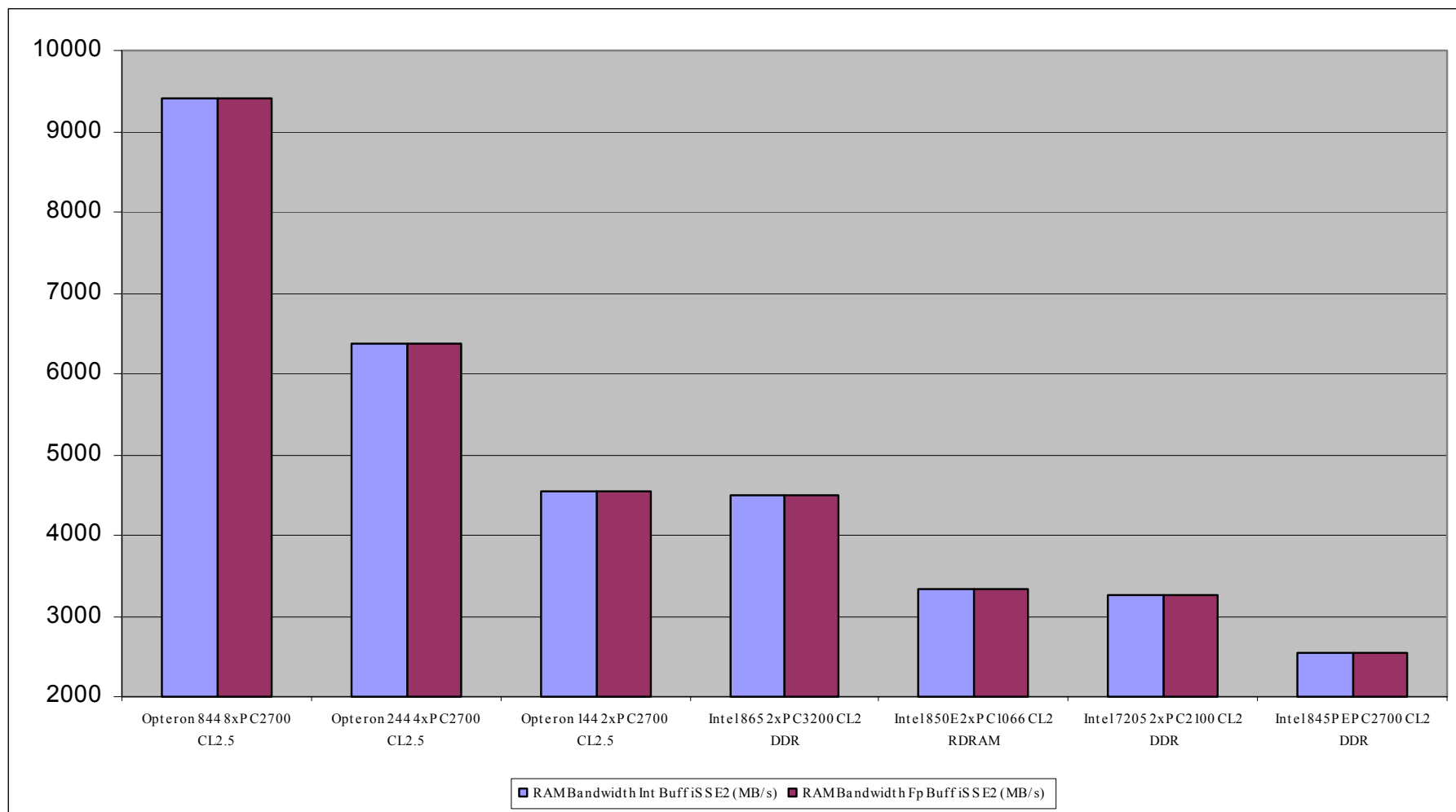
SPECfp®_peak2000 Performance (Uniprocessor)

- Itanium 2 1.0GHz — 1431 — 130%
- AMD Opteron™ 144 — 1219 — 111%
- Xeon 3.06GHz — 1103 — 100%

SPECfp®_rate2000 Performance (Peak, 2P)

- Itanium 2 1.0GHz — 30.7 — 209%
- AMD Opteron™ 244 — 26.7 — 182%
- AMD Opteron 242 — 25.1 — 171%
- AMD Opteron 240 — 22.7 — 150%
- Xeon 2.8GHz — 14.7 — 100%
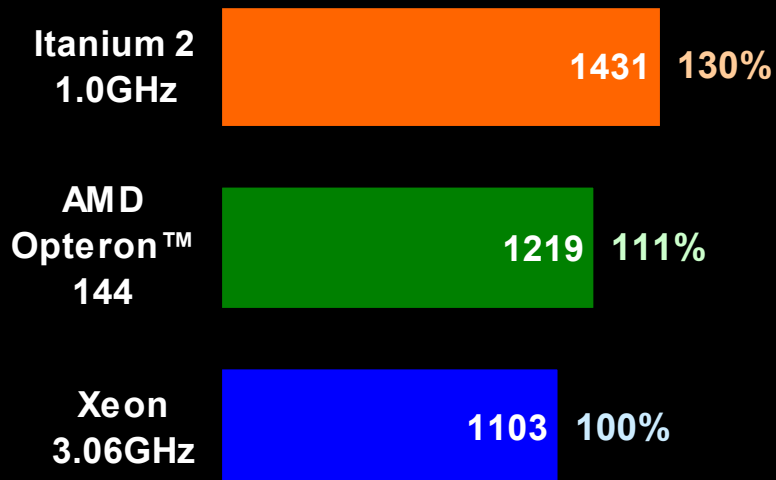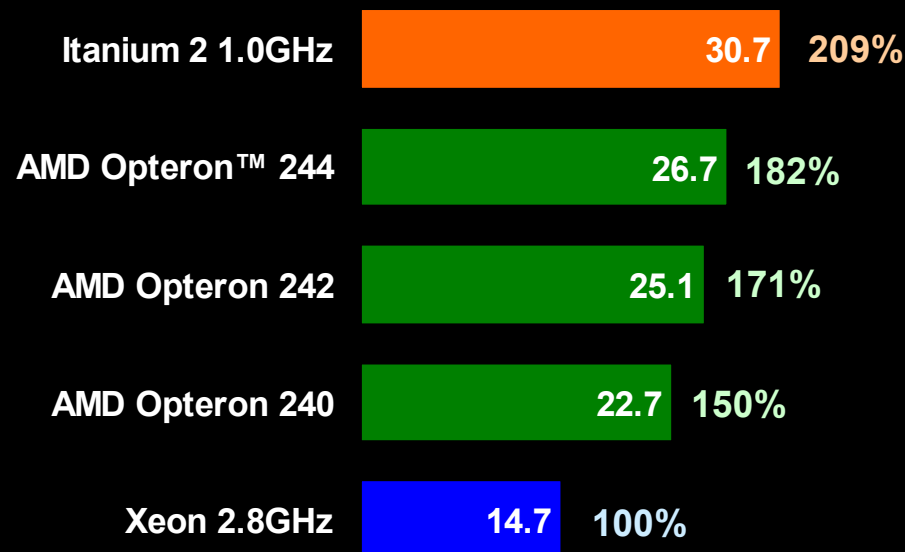
www.amd.com/opteronperformance

Floating-Point Performance

AMD

SPECfp®_rate2000 Performance (Peak, 4P)

Itanium 2 1.0GHz	49.3 **244%**
AMD Opteron™ 844	49.2 **244%**
AMD Opteron 842	45 **223%**
AMD Opteron 840	40.7 **201%**
Xeon 2.0GHz	20.2 **100%**
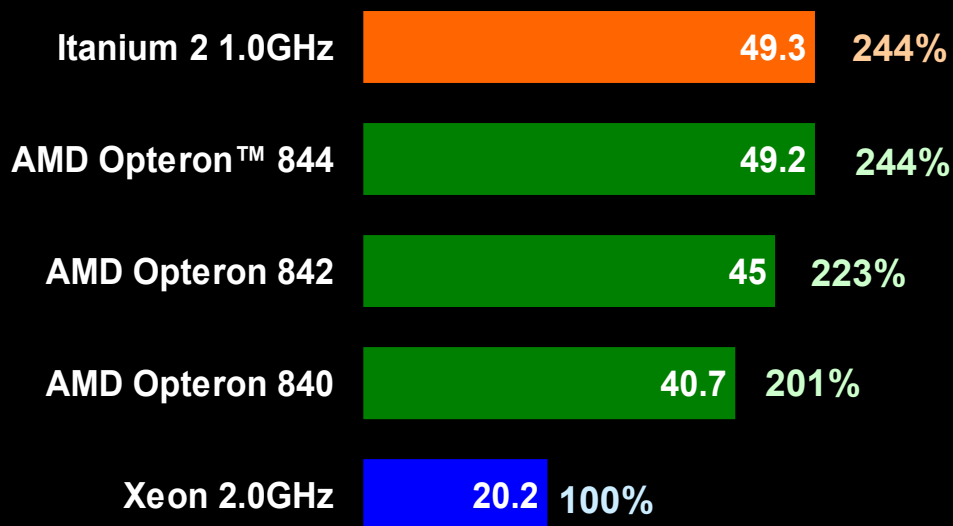
SPECfp®_rate2000 Performance and Scalability (Peak, 2-4P scaling)

Itanium 2 1.0GHz (4P)	49.3 **161%**
Itanium 2 1.0GHz (2P)	30.7 **100%**
AMD Opteron™ 844 (4P)	49.2 **184%**
AMD Opteron 244 (2P)	26.7 **100%**
Xeon MP 2.0GHz (4P)	20.2 **146%**
Xeon MP 2.0GHz (2P)	13.8 **100%**
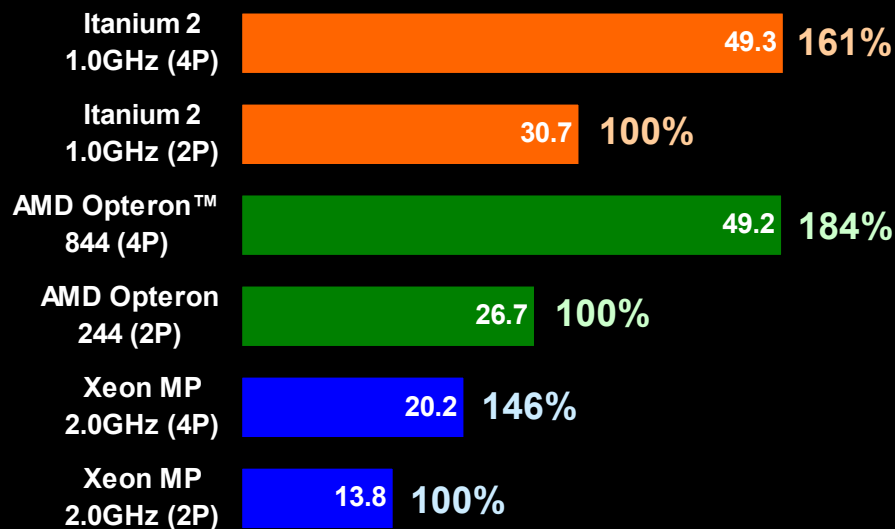
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AMD Opteron™

Web Server Performance

AMD

SPECweb®99 Performance
(2P Servers, Red Hat CA2)

Processor	Score	Percent
AMD Opteron™ 244	6250	116%
AMD Opteron 242	5800	108%
Xeon 3.06 GHz	5373	100%
AMD Opteron 240	5181	96%
Itanium 2	N/A	

SPECweb®99 Performance
(4P Servers, Red Hat CA2)

Processor	Score	Percent
AMD Opteron™ 844	10135	151%
AMD Opteron 842	9396	140%
AMD Opteron 840	8800	131%
Xeon MP 2.0 GHz	6700	100%
Itanium 2	N/A	

www.amd.com/opteronperformance

AMD Opteron™

Email Server Performance

AMD

MMB2 Performance (2P Servers, Windows®)

AMD Opteron™ 244	**11000**	**112%**
Xeon 2.8GHz	**9800**	**100%**
Itanium 2	**N/A**	

MMB2 Performance (4P Servers, Windows®)

AMD Opteron™ 844	**15520**	**118%**
Xeon MP 2.0GHz	**13200**	**100%**
Itanium 2	**N/A**	

www.amd.com/opteronperformance

AMD Opteron™

Database Server Performance

AMD

TPC-C Performance
(4P Servers, tpmC, Windows®)

Itanium 2 1.0GHz (HP rx5670)	87741	**113%**
AMD Opteron™ 844 (RackSaver QuatreX-64)	82226.46	**106%**
Xeon MP 2.0GHz (HP DL580-G2)	77905	**100%**
Xeon MP 2.0GHz (Dell PE6650)	71586.49	**92%**
Xeon MP 2.0GHz (IBM xSeries 360)	52587.46	**68%**
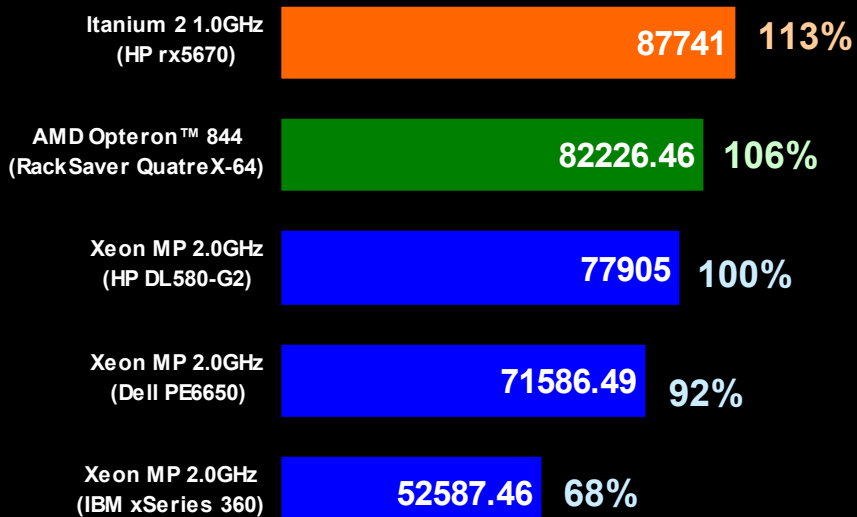
TPC-C Price/Performance
(4P Servers, $/tpmC, Windows®)

AMD Opteron™ 844 (RackSaver QuatreX-64)	$2.76	**52%**
Xeon MP 2.0GHz (IBM xSeries 360)	$4.31	**81%**
Itanium 2 1.0GHz (HP rx5670)	$5.03	**95%**
Xeon MP 2.0GHz (Dell PE6650)	$5.10	**96%**
Xeon MP 2.0GHz (HP DL580-G2)	$5.32	**100%**
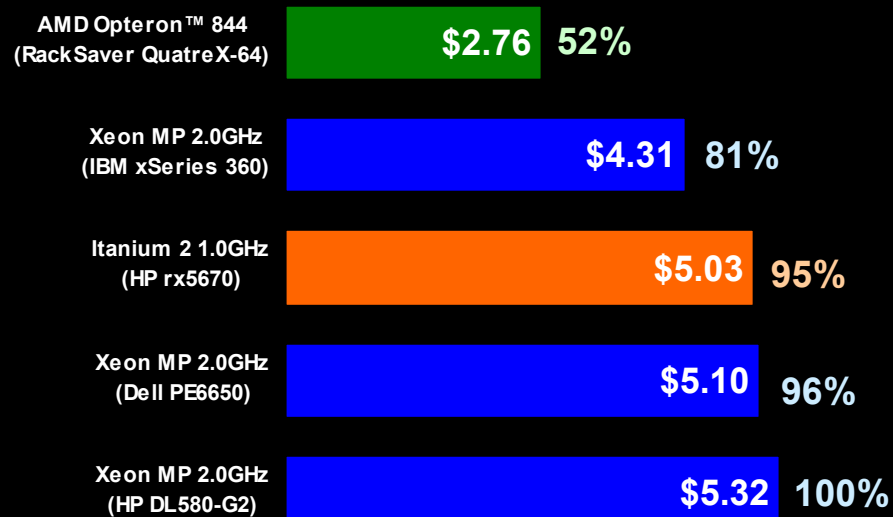
www.amd.com/opteronperformance

AMD Opteron™

Linpack – Hot off the press

AMD

AMD Opteron™ system	# P	Rmax (GFlops)	Nmax (order)	N1/2 (order)	Rpeak (GFlops)	GFLOPs/Proc	Rmax Gflops / Cycle	RPEAK/ # Procs	Peak Gflops / Cycle	Rmax / Peak
4P Melody Opteron 1.8GHz 2GB/proc PC2700 8GB Total	4	11.99	28000		14.4	3.00	1.665	3.60	2.00	83.3%
2P Melody Opteron 1.8GHz 2GB/proc PC2700 4GB Total	2	6.009	19320	616	7.2	3.00	1.669	3.60	2.00	83.5%
1P Melody Opteron 1.8GHz 2GB PC2700	1	3.042	14000		3.6	3.04	1.690	3.60	2.00	84.5%

CPU Design Clusters – From RISC to AMD64

AMD ◪

- K6 was built entirely on Sparc, PA-RISC and Power machines

- K7/Athlon was built 50% on K6 running Linux
  - Few apps. Mostly only ran in house logic simulators
  - K8/Opteron was built 80% on K7 running Linux
    - Many apps available. Only 64 bit apps conspicuously missing

- Hardware
  - Over 3000 Athlon CPUs doing back-end CAD work in California and Austin
  - Over 1500 Athlon CPUs doing front-end design world-wide
  - Non-AMD machines are used only for applications which require more memory than x86 is capable of addressing
  - Software
    - Predominantly Linux based
    - Transitioning away from non-x86 based Unix (Solaris, HP-UX, etc.)
    - 64-bit software is run on non-AMD machines

AMD

•K9 will be taped out using **only** AMD Opteron Processors

- Hardware
  - Create a homogenous compute environment
  - Anticipate over <u>8000</u> AMD Opteron/Athlon CPUs doing back-end CAD work in Sunnyvale and Austin
  - Anticipate over <u>2000</u> AMD Opteron/Athlon CPUs doing front-end design world-wide
  - AMD **<u>will not</u>** use any non-AMD 32-bit or 64-bit hardware
- Software
  - 100% Linux/LSF based throughput cluster
  - 32-bit and 64-bit applications running side by side
  - Large memory applications will scale well on Opteron – **4P = 16-32 GB of RAM**

The AMD64/Opteron Story

AMD

- The right instruction set
  - Excellent compatability
  - Excellent performance future

- The right system architecture
  - Great memory and IO capacity and bandwidth
  - Great memory latency
  - Simple "lego" system configuration

- A strong ecosystem of commodity HW and SW
  - Support chips, Software tools, motherboards

- Millions of 64 bit CPUs in 03

- 10s of millions of 64 bit CPUs in 04

Opteron Implications

AMD

- Allow more balanced scale-up/scale-out future
  - Remove 2P/4P cost barrier
  - And eventualy 8P, 16P

- Re-create the workstation
  - Constrained by 32 bit x86 on one side and slow RISC processors w/o desktop software on the other
  - 2P, 16GB, 64 bit Workstation that runs Outlook, Powerpoint and Unreal Tournament
    - 64 bit portables in 04

- X86 forever (sorry ☺)

Futures

AMD

- Moore's law continues through the decade (and beyond)
  - 90nm, 65nm, 45nm, 30nm
  - 1 Billion transistors, 4 Billion transistors
  - Vertical integration
    - It will come, first for memory
    - Gigabyte on a die goes a long way to help memory wall

- Power is the biggest issue
  - Cache, Evaporators ☺
  - Metal gate, FinFet, Adiabatic clocks, etc

- CMP is good (and obvious)

- Threading is a mixed bag
  - Latency tolerance vs. Ahmdal's law and synchronization overhead
    - Long history
  - Certainly not for execution unit utilization

Futures

AMD

- Communication barrier
  - More fundamental than memory barrier
  - Even the speed of light doesn't help (much)
  - 3D helps a lot

- Single Chip Performance (a guess)
  - 2003   5 +/- 1 Gflop   Opteron, P4, iTanium2
  - 2005   12 Gflop   2 * 6GHz
  - 2006   24 Gflop   2P * 2 * 6GHz
  - 2007   36-72 Gflop   4 * 9GHz
  - 2008   144 Gflop   4P * 4 * 9GHz

What Can You Do To Help

- Killer Apps that drive what you want
  - Games
  - Video compression/decompression
  - Face recognition as a ubiquitous app

- Keep the faith on COTS